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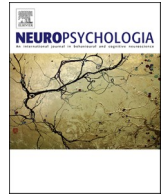
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Giving, but not taking, actions are spontaneously represented as social interactions: Evidence from modulation of lower alpha oscillations

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ABSTRACT

Unlike taking, which can be redescribed in non-social and object-directed terms, acts of giving are invariably expressed across languages in a three-argument structure relating agent, patient, and object. Developmental evidence suggests this difference in the syntactic entailment of the patient role to be rooted in a prelinguistic understanding of giving as a patient-directed, hence obligatorily social, action. We hypothesized that minimal cues of possession transfer, known to induce this interpretation in preverbal infants, should similarly encourage adults to perceive the patient of giving, but not taking, actions as integral participant of the observed event, even without cues of overt involvement in the transfer. To test this hypothesis, we measured a known electrophysiological correlate of action understanding (the suppression of alpha-band oscillations) during the observation of giving and taking events, under the assumption that the functional grouping of agent and patient should have induced greater suppression than the representation of individual object-directed actions. As predicted, the observation of giving produced stronger lower alpha suppression than superficially similar acts of object disposal, whereas no difference emerged between taking from an animate patient or an inanimate target. These results suggest that the participants spontaneously represented giving, but not kinematically identical taking actions, as social interactions, and crucially restricted this interpretation to transfer events featuring animate patients. This evidence gives empirical traction to the idea that such asymmetry, rather than being an interpretive propensity circumscribed to the first year of life, is attributable to an ontogenetically stable system dedicated to the efficient identification of interactions based on active transfer.

1. Introduction

Unlike non-human primates, among which active sharing is conspicuously rare (de Waal, 1989) and mostly limited to interactions with dependent offspring, humans regularly engage in acts of giving within and between households (Gurven and Jaeggi, 2015). Differently from other types of sharing (e.g., tolerated taking), which are opaque with respect to the prosocial intentions of the possessor (Stevens and Hauser, 2005), giving is an unambiguously altruistic action, as it requires the Giver to voluntarily pay the costs of resource transport and possession loss to increase the utility of the recipient. Costly prosocial behaviors such as giving can only evolve in a population if they produce benefits for the donor, be them direct (e.g., inducing reciprocity from past beneficiaries) or indirect (e.g., increasing the reproductive potential

of genetically related individuals; Gurven, 2004). This has direct implications for the way giving is represented in the human mind. Since its utility derives from generating benefits for others, we should expect this action to be represented in a format that captures the dependency between the Giver's action and its prosocial effects. Structurally, such a relation can be secured by making the representation of giving depend on the presence of three thematic roles: Giver, Givee, and transferred object (Tatone et al., 2015).

The idea that a well-formed representation of giving requires these three thematic roles is well-known in linguistics. Unlike the verb 'take', whose meaning is preserved even when the patient is omitted from the clause core, the verb 'give' mandates the patient to be made syntactically explicit. This requirement, which has been considered a linguistic universal (Kittilä, 2006; Newman, 1996), indicates that Giver and Givee

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are interactively connected through the act of giving, and ensures that neither could be omitted from the legal usage of the word (Newman, 2005).

Developmental evidence suggests that the inclusion of the patient role may reflect a prelinguistic understanding of giving as an obligatorily social action. Twelve-month-old infants, not yet able to produce or comprehend verbal expressions about giving, spontaneously encoded an inert Givee in the representation of observed giving events, as evinced by their sustained looking at previously familiarized Givers interacting with featurally novel recipients (Tatone et al., 2015). The encoding of the patient's identity despite the absence of cues of resource reception suggests that, beyond the possession transfer itself, infants do not require additional cues of social engagement to represent giving in interactive terms. In a recent demonstration of this claim, 15-month-olds interpreted an agent pushing an object next to a motionless recipient as an instance of goal-directed giving even when the agents were spatially separated from each other, and the transfer may have been perceived as side effect of the agent's pursuit of a different goal (Tatone et al., 2019).

Infants' striking readiness to infer social interactions on the basis of minimal cues of benefit conferral does not generalize however to other transferring actions. When familiarized with taking events kinematically identical to giving, infants did not include the Takee in their event representation, favoring instead an interpretation of the Taker's goal as purely object-directed (Tatone et al., 2015). Such difference is consistent with the idea that, while the goal of giving can only be understood with reference to its effects on the recipient's welfare, the social consequences of taking (i.e., the expropriation of the Takee's possession) do not need to be factored in to interpret the action as goal-directed. Owing to this asymmetry, the interactive interpretation of giving is systematically privileged over non-interactive ones, whereas for taking, in which an object-directed goal hypothesis is readily available, such interactive interpretation is neither compulsory nor prioritized. The developmental findings thus suggest that the differences in syntactic requirements between giving and taking may reflect early-developing asymmetries in the representational format of these actions. If so, we should expect adults to show the same asymmetric interpretation found in preverbal infants, independent of linguistic mediation.

In the present study, we tested this hypothesis by presenting adult participants with animated giving and taking events, in which an active agent (Giver or Taker) transferred a resource to or from a patient (Givee or Takee), who remained motionless throughout the transfer. By employing transfer events featuring inactive patients, we sought to additionally examine whether, similarly to infants, our participants would spontaneously perceive giving-based interactions exclusively on the basis of the possession transfer (i.e., in the absence of behavioral cues of resource request or reception). Crucially, this interpretation should only be available when the recipient is an animate patient. To assess the specificity of this interpretation, we compared giving events to kinematically identical displacement events featuring an inanimate object (a rock) as 'recipient.' Since animate objects can fulfill the role of destination but not that of recipient (cf. Ziegler and Snedeker, 2018), we expected that these events would not be represented in interactive terms. Conversely, in the taking case, if adults (like infants) privileged a purely object-directed interpretation of the transfer, manipulating the animacy status of the patient should not affect the resulting representation.

To investigate how the participants interpreted giving and taking events we exploited the mu rhythm (also known as the sensorimotor alpha rhythm, 8–13 Hz) as measure of the perceived interactivity of the observed action. This EEG component has been suggested to reflect action understanding (for reviews: Fox et al., 2016; Muthukumaraswamy et al., 2004; Naeem et al., 2012; Oberman et al., 2007; Ulloa and Pineda, 2007). Attenuation of this rhythm around central and parietal cortices has been observed when people execute, or observe others execute, transitive goal-directed actions (Muthukumaraswamy and Singh, 2008). However, stronger attenuation of the mu rhythm has been also reported

during the observation of interdependent actions (coordinated chasing) relatively to two independent actions (solo chasing: Yin et al., 2017). This evidence suggests that the mu rhythm may be additionally sensitive to the functional grouping of multiple agents within interactive units (Canessa et al., 2012; Centelles et al., 2011). If so, the attenuation of alpha oscillations could be used to assess the perceived level interactivity of observed actions, under the assumption that interactive action interpretations would induce stronger attenuation than non-interactive ones (Oberman et al., 2007). Moreover, given that attenuation of lower alpha (8–10 Hz) has been shown to more sensitively reflect action interpretation (Dumas et al., 2014; Frenkel-Toledo et al., 2014), we should expect mu rhythm attenuation to be more conspicuously detectable within these bands.

On the basis of our hypothesis, our predictions were as follows: if adults spontaneously represent giving, but not taking, as a social interaction (even when featuring motionless recipients), observation of the former should induce stronger alpha attenuation. Importantly, however, such a difference should be restricted to events featuring animate patients.

2. Methods

2.1. Participants

Sixteen paid volunteers (9 males and 7 females; mean age = 21 years, age range = 19–25 years) participated in this experiment. They all had normal or corrected to normal vision without history of neurological disorders. Three additional adults were excluded because they produced fewer than half of the trials artifact-free (2 participants), or erroneously considered the 'rock' in our stimuli as an animate agent (1 participant). The sample size was determined prior to data collection on the basis of studies using similar EEG measures to evaluate action understanding (Pomiechowska and Csibra, 2017). The experiment was approved by the United Ethical Review Committee for Research in Psychology (EPKEB) in Hungary, and was performed in accordance with the relevant guidelines and regulations. All participants received written information about the study and gave informed consent.

2.2. Apparatus and stimuli

The stimuli were computer-generated animations presented on a 19-inch CRT monitor (resolution 800 × 600 pixels; refresh rate 100 Hz) from 100 cm viewing distance. The stimuli appeared in the center of the screen (11.1° × 8.3°) on a black background. The animations were created in Blender (<https://www.blender.org>), and their presentation was controlled by a custom-built script written using The Psychophysics Toolbox (Brainard, 1997) for Matlab.

The stimuli were 2-s-long animations, displayed in the center of the screen (11.1° × 8.3°). Each event included two featurally different animate characters (an active agent, hereafter 'agent', and a still agent, hereafter 'patient'), a rock, and an apple. We used 9 different 3D shapes as agents, each rendered with distinctive textures. Across trials, agents were paired in all possible ways, resulting in 36 different pairs. All animations were presented from 12.2° viewing distance and 73° perspective view in 3D.

The animations differed along two factors: (1) the action type (*transferring* or *collecting*) depending on the direction in which the agent carried the apple, and (2) the target, which was either the animate patient or the rock. The crossing of these two factors resulted in four types of events: Transferring the apple to the patient (*giving*), transferring the apple to the rock (*disposing*), collecting the apple from the patient (*taking*), and collecting the apple from the rock (*acquiring*). Each event began with the agent located 1.6° above the center of the stage (subtending 11.1° × 7.1°), the patient in the left or right lower side of the stage (counterbalanced across trials within a subject) at a distance of 2.8° from the center of the stage, and the rock, on the other side of the stage,

mirroring the patient's location. During the *giving* event, the agent pushed the apple from the upper side to the lower side of the stage for a distance of about 2.8° (0.5 s), turned left or right towards the patient (0.1 s), continued its motion towards the patient, deposited the apple in front of it (0.5 s), and finally returned to its initial position (0.9 s). The *disposing* event was kinematically identical to *giving*, except that the agent pushed the apple in front of the rock. In *taking* and *acquiring* events, the agent's motion path was the same as in the previous events, but the apple was collected from the patient or the rock, respectively. The patient never moved, whether or not it was the goal or source of the agent's transferring action.

Additionally to these events, the participants were also presented with catch trials consisting of animations in which the agent was made invisible for a time window of 0.8 s, randomly chosen between 0.3 s after stimulus onset and 1.7 s before stimulus offset.

2.3. Procedure

The participants were instructed to watch the animations and count the number of catch trials within each block. Each trial started with a dynamic fixation stimulus at the center of the screen, first moving (480 ms) and then immobile (300 ms–400 ms, randomly determined). This fixation stimulus was replaced by the first frame of the animation (displayed for 300 ms), and followed by the animation for 2 s. Between trials a black screen was presented for a variable interval between 900 and 1100 ms (see Fig. 1). For each participant, the 36 different pairs of agents were randomly divided into two groups to present transferring and collecting actions. The same pairs of agents featured in *giving* and *disposing* events, as well as in *taking* and *acquiring* events. The resulting 72 trials were presented in pseudorandom order, with the restriction that the same type of event was never repeated for three consecutive trials. Four blocks were included. Eight or 12 catch trials were randomly inserted in each block, with the restriction to be never presented in the first or last trial, as well as in two consecutive trials. Subjects were asked to count how many catch trials were included in a block. If the reported estimate was two point higher or lower than the actual number of catch trials, the data from such block were rejected. However, no block was rejected for this reason.

2.4. EEG recording and analyses

High-density EEG was recorded continuously using Hydrocel Geodesic Sensor Nets (Electrical Geodesics Inc.), incorporating 128 electrodes referenced to the vertex (Cz). Signals were acquired using an EGI amplifier (GES 300) at a sampling rate of 500 Hz with a low-pass filter at 200 Hz. The EEG was offline band-pass filtered between 0.3 and 30 Hz and segmented into epochs around each trial. Each epoch started 0.5 s before animation onset and finished 0.2 s after the animation offset, lasting 2.7 s in total. EEG epochs were automatically rejected as artifacts whenever the average amplitude of a 80 ms gliding window exceeded $55 \mu\text{V}$ at horizontal EOG channels, $140 \mu\text{V}$ at vertical EOG channels, or $200 \mu\text{V}$ at any other channel. The participants contributed on average 55 artifact-free trials to the *giving* condition, 55 to the *disposing* condition, 54 to the *taking* condition, and 56 to the *acquiring* condition.

To measure oscillatory EEG responses, the artifact-free segments were subjected to frequency analysis in Matlab. The epochs were first re-referenced to the average reference. Then, using the Fieldtrip toolbox (Oostenveld et al., 2011), the integrated amplitude for each epoch in the 5–20 Hz range was computed through a Fast Fourier Transform (FFT) performed at 0.5 Hz intervals (using a Hanning window) for the spectral analysis. Alpha-band oscillations were measured separately in the lower (8–10 Hz) and upper (11–13 Hz) alpha band (Dumas et al., 2014; Frenkel-Toledo et al., 2014). Because alpha attenuation during action observation has been reported to occur over broad areas of the centro-parietal cortex on both sides (Debnath et al., 2019; Fox et al., 2016), we quantified the amplitude of both frequency bands over these regions as the average amplitude across epochs. Based on the electrode grouping recommendations by Goodin et al. (2012) and Butler and Trainor (2012), we selected channels for the right and left centro-parietal areas as 77–80, 85–87, 91–93, 97–98, 103–106, 110–112; and 7, 13, 29–31, 35–37, 41–42, 47, 51–54, 59–61, 67; respectively.

To get more precise information about the dynamics of the alpha-band activity, we calculated event-related desynchronization (ERD) using time-frequency analysis. The epochs were re-referenced to average reference and were convoluted by continuous complex Morlet wavelets between 5 Hz and 20 Hz with 1 Hz resolution using a custom-made script collection WTools (available on request). The absolute values of the complex coefficients were computed and averaged across trials within each condition, and the resulting values were baseline-corrected to the 300 ms preceding stimulus onset. We measured the lower alpha-band ERD between 8 and 10 Hz at the same two ROIs used in the FFT analyses in the window of 600–1000 ms after stimulus onset. This time window corresponded to the period when the agent started moving towards either the patient or the rock - i.e., the moment when the two different types of actions could be distinguished from each other.

3. Results

The alpha attenuation in response to our stimuli was evaluated separately in the two frequency bands for each analysis type.

3.1. Spectral analysis

Lower alpha band. Fig. 2c depicts the average amplitude in the 8–10 Hz band as a function of condition and hemisphere. A three-way ANOVA with hemisphere (left vs. right), action type (transferring vs. collecting) and target (patient vs. rock) as within-subjects factors on the amplitude of lower alpha oscillations revealed a three-way interaction effect ($F(1,15) = 6.31, p = .024, \eta_p^2 = .30$). Exploring this interaction, we found a significant two-way interaction effect between action type and target over the right hemisphere ($F(1,15) = 8.35, p = .011, \eta_p^2 = .36$), but not over the left hemisphere ($F(1,15) = 0.42, p = .526, \eta_p^2 = .03$). Post-hoc two-tailed simple effect analyses showed that *giving* events induced stronger attenuation of lower alpha activity than *disposing* events ($F(1,15) = 6.22, p = .025, \eta_p^2 = .29$) over the right hemisphere, while no such difference emerged in *taking* vs. *acquiring* ($F(1,15) = 0.83, p = .376, \eta_p^2 = .05$). Furthermore, the *giving* events tended to induce

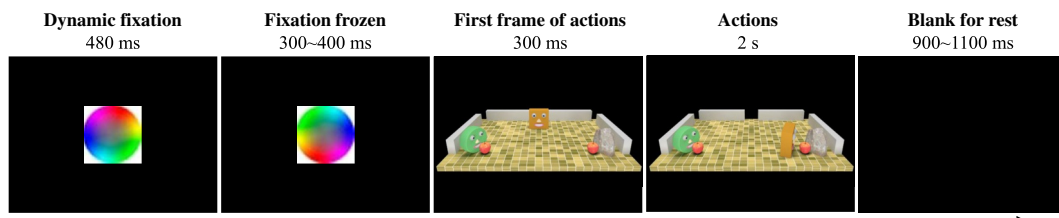


Fig. 1. The timing of stimulus phases.

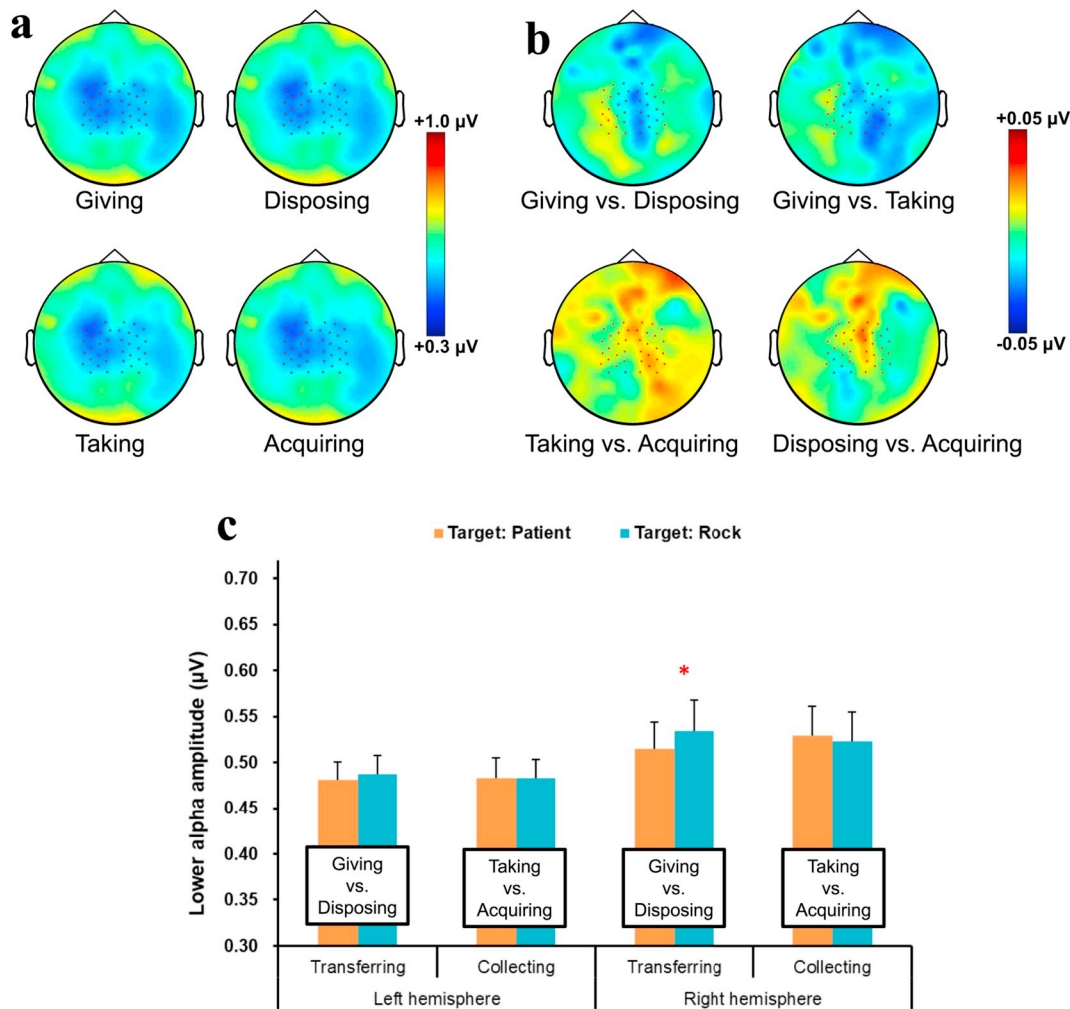


Fig. 2. Lower alpha (8–10 Hz) amplitude responses in the spectral analyses. (a) Spatial distribution of each condition over the scalp. Dots represent the electrode locations used for quantifying responses depicted in (c). (b) Topographic maps of the amplitude difference in the responses between actions (giving *minus* disposing, taking *minus* acquiring, giving *minus* taking, and disposing *minus* acquiring). (c) Amplitudes measured over the centro-parietal cortex as a function of condition and hemisphere. Error bars represent standard error of the mean.

stronger lower alpha attenuation than the *taking* events over the right hemisphere ($F(1,15) = 4.46, p = .052, \eta_p^2 = .23$). We also found differential alpha attenuation between the two non-social events, where the target of the action was a rock: *acquiring* events induced stronger lower alpha attenuation than *disposing* events over the right hemisphere ($F(1,15) = 8.21, p = .012, \eta_p^2 = .35$). Fig. 2a and b show that the presence of an animate patient induced lower alpha amplitude only during the observation of *transferring*, but not *collecting*, actions, thus suggesting that the participants included the motionless recipient in their event representation.

Upper alpha band. Fig. 3c depicts the average amplitude in the upper alpha band as a function of condition and hemisphere. Fig. 3a represents the topographic maps for the four events, and 3b represents the topographic maps of the difference of upper alpha band between target types (patient *minus* rock) separately for *transferring* and *collecting* events. We performed the same analyses on the amplitude of the upper alpha band as for the lower alpha band. This revealed an interaction effect of hemisphere and action ($F(1,15) = 5.62, p = .032, \eta_p^2 = .27$). Post-hoc simple effect analyses showed that the amplitude of upper alpha oscillations was marginally higher over the right hemisphere in the *collecting* condition ($F(1,15) = 4.18, p = .059, \eta_p^2 = .22$), whereas no difference emerged in the *transferring* condition ($F(1,15) = 2.49, p = .135, \eta_p^2 = .14$). There was no other significant effect ($ps > .085$).

3.2. Time-frequency analysis

Lower alpha band. As shown in Fig. 4 and Fig. 5, the ERD in the lower alpha band confirms the results of the spectral analysis. We performed a three-way ANOVA with hemisphere (left vs. right), action type (*transferring* vs. *collecting*), and target (patient vs. rock) as within-subject factors on the amplitude of lower-alpha oscillations during the time when the agent approached the target (600–1000 ms after onset of the animation). This analysis yielded a significant three-way interaction between hemisphere, action type, and target, ($F(1,15) = 4.76, p = .046, \eta_p^2 = .24$). This interaction effect was due to a two-way interaction between action type and target being significant only over the right ($F(1,15) = 4.80, p = .045, \eta_p^2 = .24$), but not over the left hemisphere ($F(1,15) = 0.13, p = .721, \eta_p^2 = .01$). Analyzing this interaction further, we found that *giving* induced stronger alpha attenuation than *disposing* ($F(1,15) = 4.74, p = .046, \eta_p^2 = .24$). No such difference was found between *taking* and the *acquiring* ($F(1,15) < 0.01, p = .961, \eta_p^2 < .01$). Furthermore, *giving* induced stronger attenuation than *taking* ($F(1,15) = 6.85, p = .019, \eta_p^2 = .31$), whereas *acquiring* did not produce stronger alpha attenuation than *disposing* ($F(1,15) = 0.54, p = .474, \eta_p^2 = .04$).

Upper alpha band. Fig. 6c depicts the average amplitude in the upper alpha band as a function of condition and hemisphere. Fig. 6a and 6b represents the topographic maps for different conditions. We performed the same analyses on the amplitude of the upper alpha band as

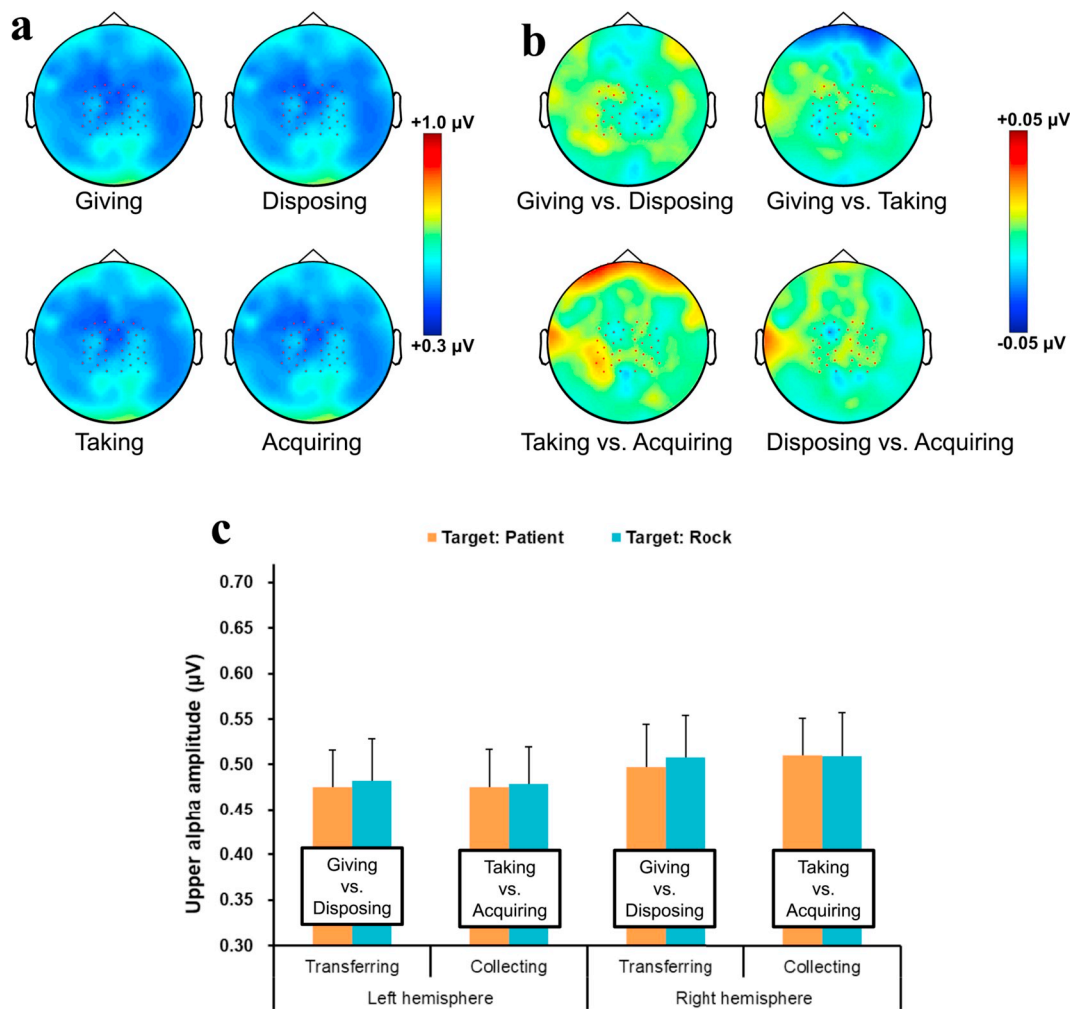


Fig. 3. Upper alpha (11–13 Hz) amplitude responses in the spectral analyses. (a) Spatial distribution of each condition over the scalp. Dots represent the electrode locations used for quantifying responses depicted in (c). (b) Topographic maps of the amplitude difference in the responses between actions (giving *minus* disposing, taking *minus* acquiring, giving *minus* taking, and disposing *minus* acquiring). (c) Amplitudes measured over the centro-parietal cortex as a function of condition and hemisphere. Error bars represent standard error of the mean.

we did for the lower alpha band. This analysis revealed that none of the effects was significant ($ps > .210$).

3.3. Exploratory analyses

To assess whether alpha-band modulation was restricted to the centro-parietal regions, we performed additional analyses over frontal and occipital areas, which yielded no significant interaction effect between action type and target at either area. These analyses and results are reported in the Supplementary Material.

4. Discussion

The primary aim of the present study was to investigate whether people spontaneously perceive giving, but not taking, events as social interactions solely on the basis of cues of possession transfer. To this end, we measured the attenuation of alpha-band oscillations, a known index of action understanding, in a sample of adult participants during the observation of abstract transfer events featuring motionless patients. Since the representation of social interactions requires the tracking of multiple participating agents (Canessa et al., 2012; Centelles et al., 2011), we reasoned that alpha attenuation should be more pronounced for actions perceived in interactive terms. Confirming our prediction, stronger suppression was observed during the observation of *giving*, but

not of *taking*, events. Importantly, a similar suppression also emerged for *giving* compared to *disposing*, whereas no difference was found between *taking* and its non-social equivalent (*acquiring*). This action-specific suppression pattern was observed in both spectral and time-frequency analyses. In addition to the finding that *giving* induced more alpha attenuation than *taking* or *disposing*, we also found unexpectedly that *acquiring* induced stronger attenuation than *disposing*. We hypothesize that this effect is explained by the known effect of stronger alpha attenuation induced by the observation of goal-directed over non-goal-directed actions (e.g., Muthukumaraswamy et al., 2004; Pomiechowska; Csibra, 2017), and that the acquisition of an object is a more easily interpretable goal than its disposal.

Taken together, these findings corroborate our main hypothesis: consistently with the infant data, our participants spontaneously interpreted giving as a constitutively social action, whereas they interpreted taking in purely object-directed terms. Such difference reflects the asymmetric role that the patient plays in each transfer events: while the goal of giving could be meaningfully understood only through its effects on the patient's welfare (as it would otherwise result in a costly instance of resource loss), the goal of taking can be immediately apprehended even if such effects are not considered. In other words, taking actions can be interpreted as directed to the goal of resource acquisition, whether the concomitant loss of the Takee's possession is taken into account or not. The availability of such a structurally simpler interpretation for the

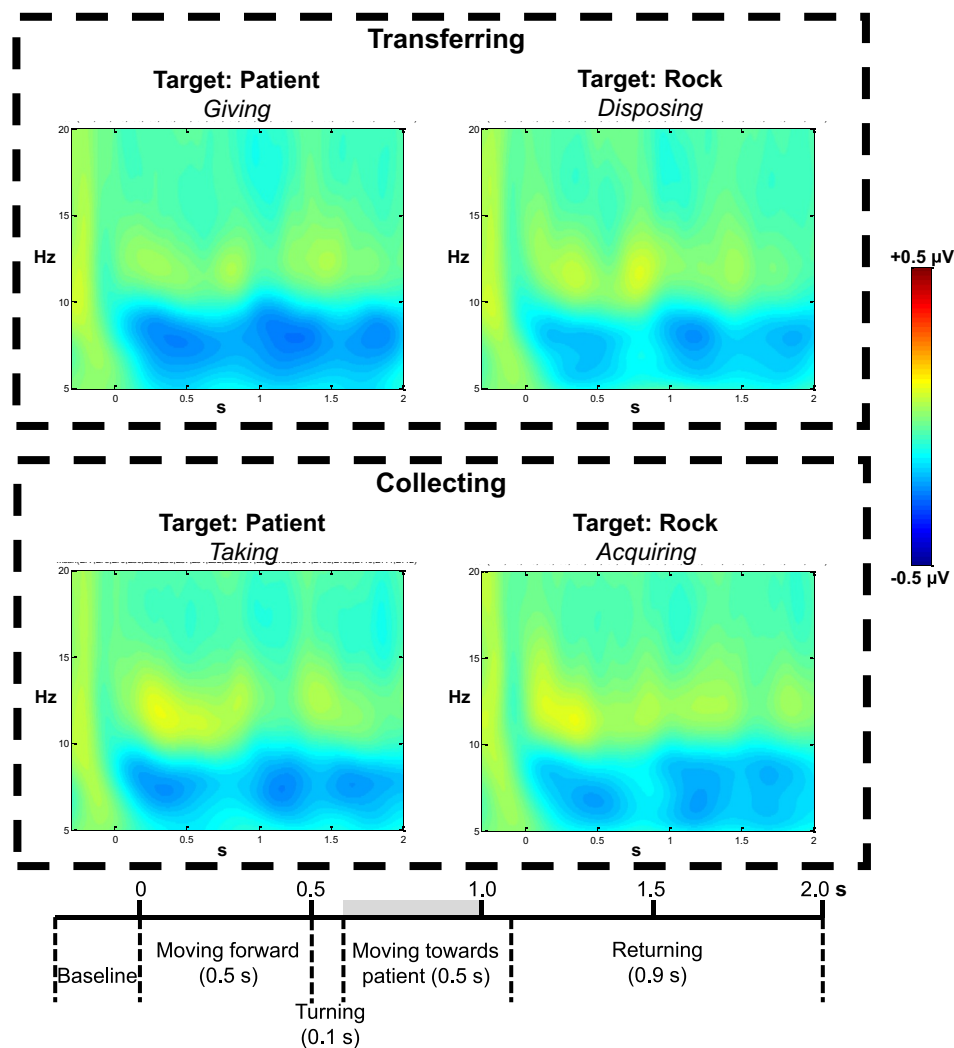


Fig. 4. Event-related desynchronization of lower alpha oscillations over the right hemisphere. The timeline at the bottom of the figure depicts the event sequence, and the gray bar indicates the time window used for quantifying the ERD response.

taking action may explain why the participants failed to discriminate between social and non-social acts of resource collection, as suggested by the absence of differential lower alpha attenuation in the *taking* vs. *acquiring* comparison.

By presenting our participants within each condition with transfer events differing only with respect to the recipient's animacy status (a patient vs. a rock) we were able to rule out the possibility that alpha attenuation could have been induced not by the interactive nature of giving but by other non-social factors, such as the selective encoding of entities featuring as movement endpoints (goal bias: Lakusta and Landau, 2012; Reghier and Zheng, 2007). Importantly, despite the recipient's animacy was similarly manipulated in the collecting condition, *taking* did not produce stronger attenuation than *acquiring* events. This suggests that the modulation of lower alpha amplitude did not index the presence of an additional agent per se, but rather the role this played within the interaction.

It is worth noting that the perception of the patient as event participant in giving could not have been induced by overt cues of social engagement, as the patient remained motionless throughout the transfer. Rather, its integration automatically occurred upon identifying the transferring event as an instance of giving, the representation of which requires the functional grouping of two agents and their assignment to complementary action roles. Mirroring infants' propensity to include inert patients in the representation of giving events (Tatone et al., 2015;

2019), our data thus suggests that adults' concept of giving is based on the same few cues that are responsible for its priming in the first years of life. The comparable preparedness of infants and adults to perceive dyadic interactions behind such skeletal stimuli seems evidence of an ontogenetically conserved sensitivity to basic cues of resource transfer.

The modulation effects we observed were localized around centroparietal regions of the scalp. Several fMRI studies, in contrast, reported a more posterior temporal activation (involving the posterior part of the superior temporal sulcus, pSTS) during the observation of third-party encounters (reviewed in: Quadflieg and Koldewyn, 2017). This literature shows that pSTS activity responds to several dimensions of action analysis, such as whether agents have interdependent or individual goals (Centelles et al., 2011), occupy symmetric or complementary action roles (Georgescu et al., 2014), or relate to each other in a cooperative or competitive manner (Walbrin et al., 2018). A study that, just like ours, used animated geometrical figures to investigate neural activations related to the perception of actions also found pSTS activation specifically elicited by social interactions compared to individual actions or physical interactions (Isik et al., 2017). Our results go beyond this study by demonstrating sensitivity to social interactions when such an interpretation of the events is not couched merely in terms of action kinematics. In this respect, our study is the first to rigorously equate the low-level visual features of the events compared (*giving* vs. *taking*; or *giving* vs. *disposing*). Such a kinematically matched contrast is difficult to

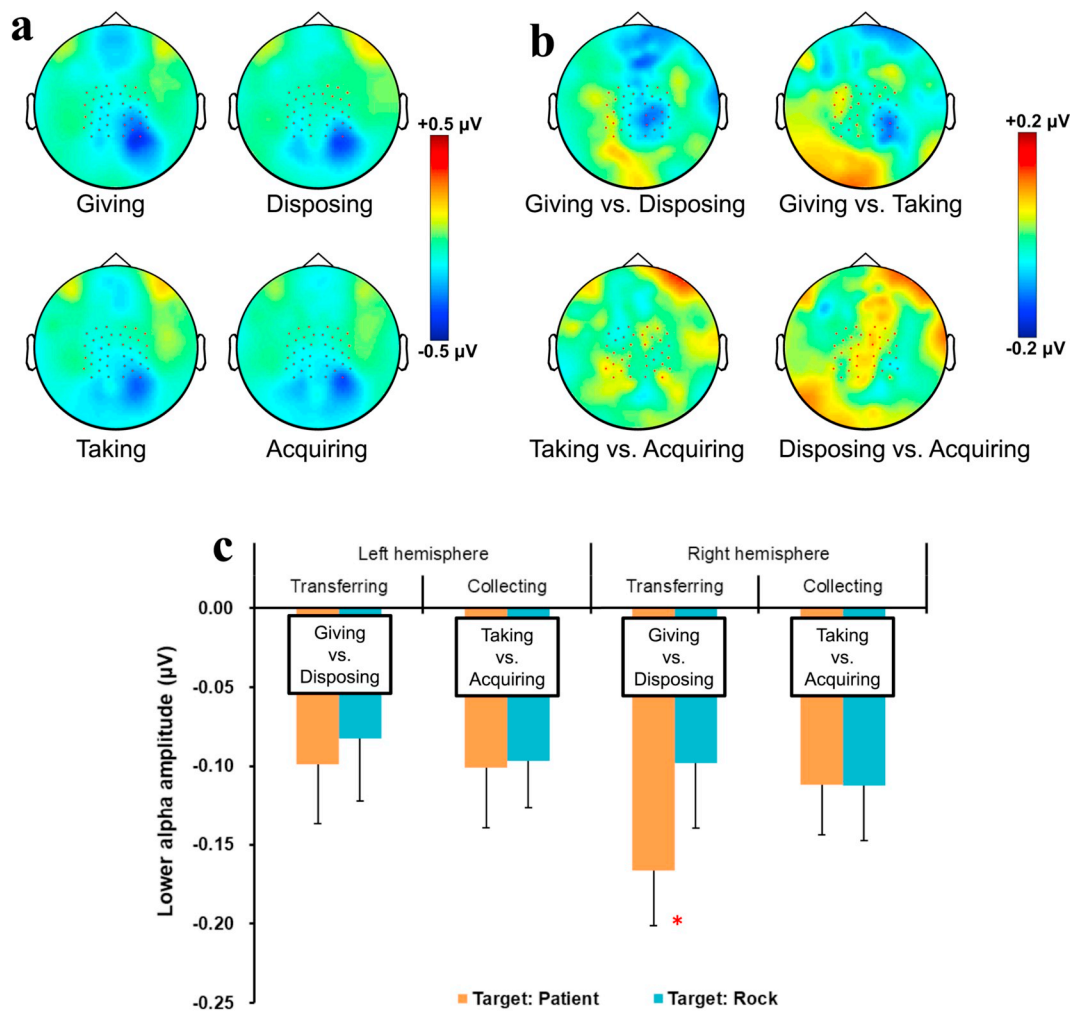


Fig. 5. Lower alpha ERD responses in the time-frequency analyses. (a) Spatial distribution of each condition over the scalp. Dots represent the electrode locations used for quantifying responses depicted in (c). (b) Topographic maps of the amplitude difference in the responses between actions (giving *minus* disposing, taking *minus* acquiring, giving *minus* taking, and disposing *minus* acquiring). (c) ERDs measured over the centro-parietal cortex as a function of condition and hemisphere. Error bars represent standard error of the mean.

achieve with actions performed by human actors, which also preferentially engage the pSTS when embedded in social interactions (Wurm et al., 2017).

While our findings concur with other studies by demonstrating that certain brain activations reflect fine-grained interpretation of social interactions, we find it unlikely that the lower alpha attenuation measured on the scalp originates directly from the pSTS. Rather, alpha attenuation reflected sensorimotor activation related to the tracking of the unfolding actions of the observed agents (Yin et al., 2017), which is down-stream from, and probably influenced by, the interpretation of the events generated by computations in the pSTS. Our study can be more closely compared to that of Yin et al. (2017), which reported stronger alpha suppression during the observation of coordinated chasing events. The similarity of the findings despite the radically different cues used to induce the perception of a social interaction (in their study, cues of jointly efficient coordination towards a common target; in the present study, cues of resource transfer) substantiates the claim that modulation of alpha-band oscillations may reflect the tracking of multiple agents in a functional interactive unit, irrespectively of the particular cues bringing about such grouping. To test this proposal, we performed an additional experiment that attempted to establish whether dyadic interactive chasing would produce stronger alpha attenuation than comparable stimuli (see the Supplementary Material for details).

In conclusion, we provided neural evidence that adults, similarly to

infants, spontaneously interpreted giving, but not taking, actions as instances of social interactions, even when entirely devoid of cues of social engagement. This evidence corroborates our proposal that such asymmetry, rather than being an interpretive propensity circumscribed to the first year of life, is attributable to an ontogenetically stable system dedicated to the efficient identification of interactions based on resource transfer. Under such reading, cross-linguistic differences in the syntactic requirements of giving and taking verbs may conceivably reflect pre-linguistic assumptions about the number of obligatory event participants that each action concept entails (Newman, 1996).

An empirically adequate validation of our hypothesis about the spontaneous social binding of Giver and Givee in an interactive unit will however require complementation of the neural evidence with behavioral data. The growing literature on the perceptual grouping of minimally or potentially interactive units (typically operationalized as static images of actors facing each other, either standing still or frozen in incipient transitive actions) suggests that the effects of such social binding should be observable across a number of cognitive processes, such as detection accuracy (Papeo et al., 2019), configural processing (Papeo et al., 2017), spatial estimation, feature detection (Vestner et al., 2019), and working-memory chunking (Ding et al., 2017). Future studies should aim at investigating whether our skeletal implementation of transfer events can indeed produce any such behavioral signatures of social binding, and do so specifically for acts of giving.

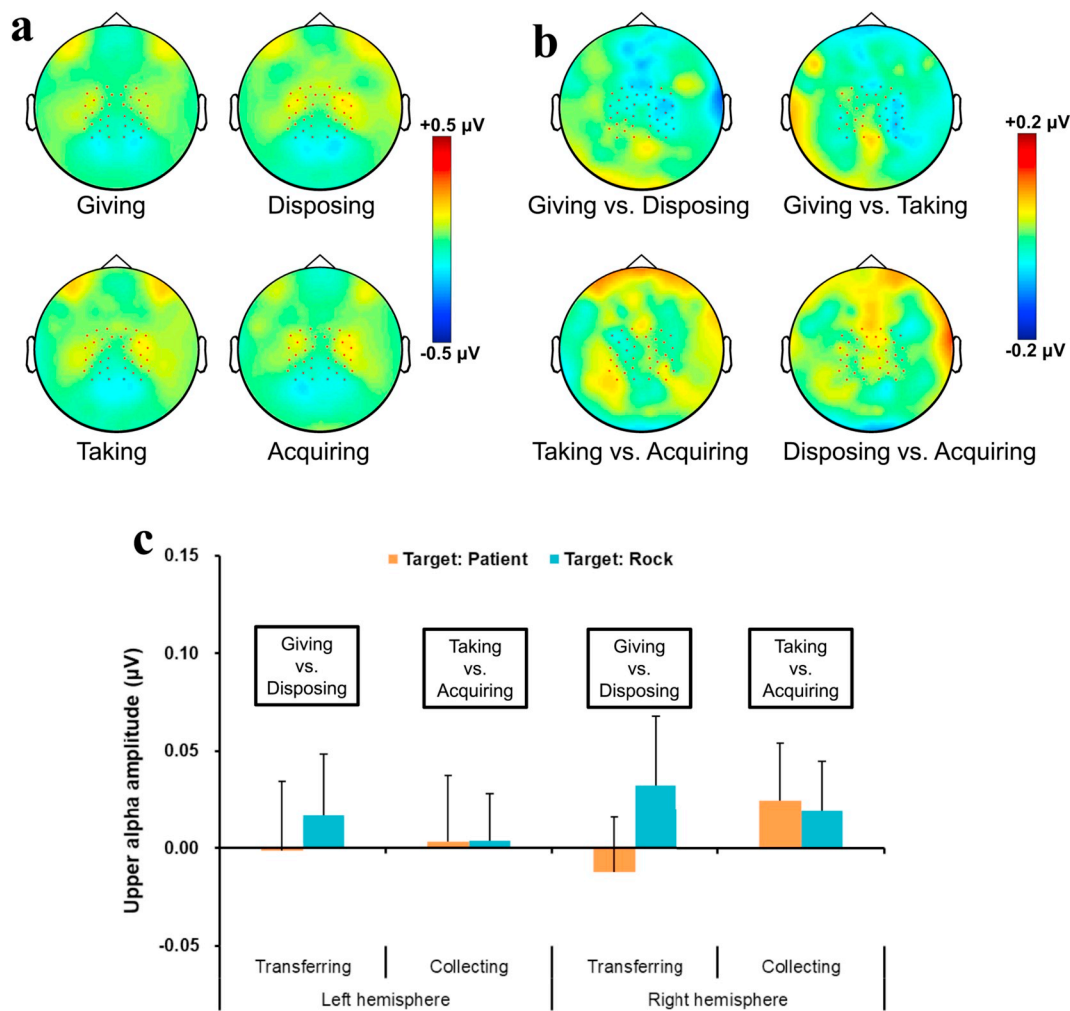


Fig. 6. Upper alpha ERD responses in the time-frequency analyses. (a) Spatial distribution of each condition over the scalp. Dots represent the electrode locations used for quantifying responses depicted in (c). (b) Topographic maps of the amplitude difference in the responses between actions (giving *minus* disposing, taking *minus* acquiring, giving *minus* taking, and disposing *minus* acquiring). (c) ERDs measured over the centro-parietal cortex as a function of condition and hemisphere. Error bars represent standard error of the mean.

CRedit authorship contribution statement

Jun Yin: Conceptualization, Methodology, Formal analysis, Investigation, Writing - original draft. **Denis Tatone:** Conceptualization, Writing - review & editing. **Gergely Csibra:** Conceptualization, Writing - review & editing.

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Appendix A. Supplementary data

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